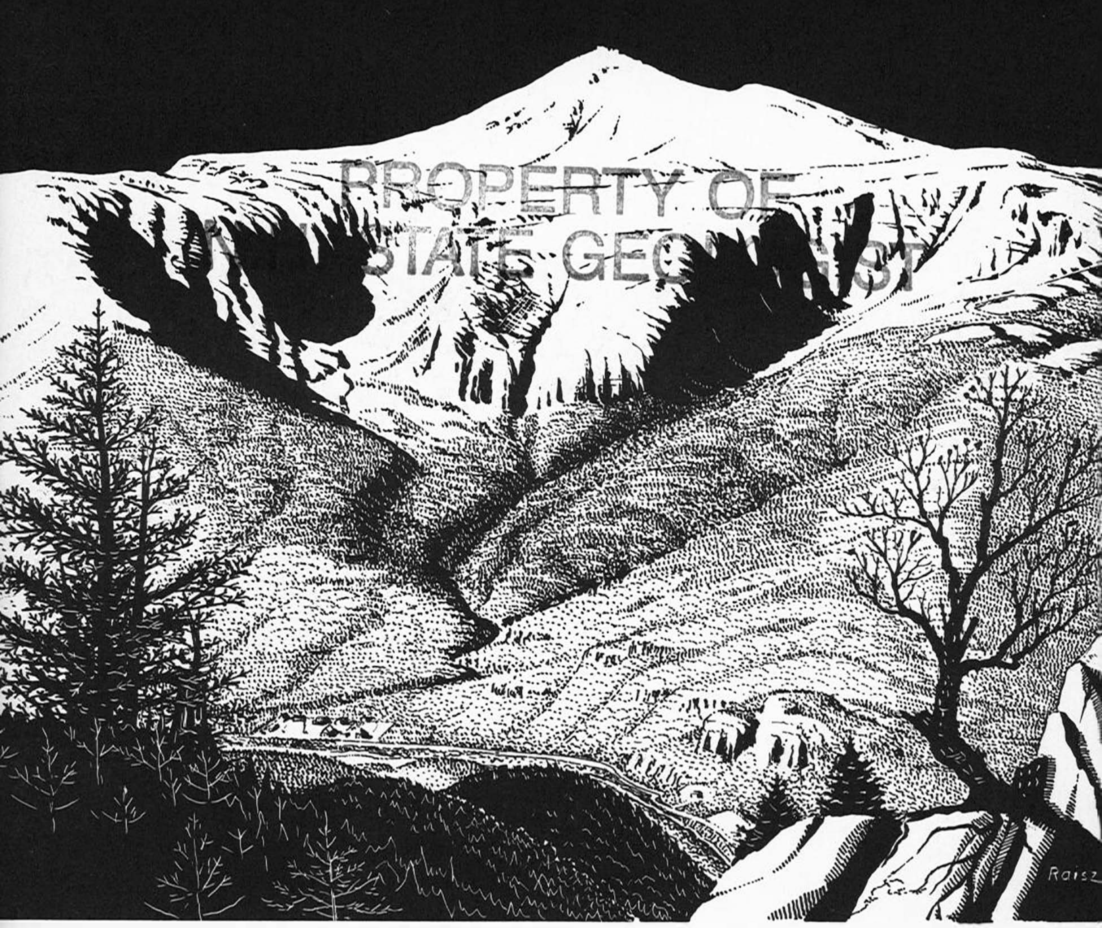

THE GEOLOGY OF THE
Mt. Washington Quadrangle
NEW HAMPSHIRE

by

**Marland P. Billings, Katharine Fowler-Billings, Carleton A. Chapman
Randolph W. Chapman and Richard P. Goldthwait**

PUBLISHED BY THE NEW HAMPSHIRE PLANNING AND DEVELOPMENT COMMISSION

1946

Figure 1 — Aerial view of Mt. Washington from the west showing steep V-shaped ravines cut by mountain streams. Bretton Woods is in the foreground. Mt. Adams is the peak at the extreme left. The white gash on the slopes of Mt. Washington is the Cog Railroad. (Photo by H. Bradford Washburn, Jr. Courtesy of the Flume Reservation, Franconia Notch, N. H.)

The Geology of the Mt. Washington Quadrangle

New Hampshire

By MARLAND P. BILLINGS, KATHARINE FOWLER-BILLINGS,
CARLETON A. CHAPMAN, RANDOLPH W. CHAPMAN
AND RICHARD P. GOLDTHWAIT

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FOREWORD

This pamphlet presents the story of the rocks of the Mount Washington quadrangle. The history of the mountains, the formation of the rocks, their folding and uplift, and their shaping by the work of streams and ice is told in simple language for the layman. Few scientific names are used. The colored map accompanying the pamphlet shows the topography of the region as well as details of the geology, with a legend for interpreting the maps. All that need concern the layman are the formation names. It is not essential for him to read or understand the detailed mineral and rock descriptions. The fascinating story of the rocks can be understood without these details.

The Mount Washington region has long been of interest to the geologist, and many workers have contributed their share in the study of this area. It has been possible to include descriptions of only a few choice localities in these pages. A partial bibliography is found at the back of this pamphlet for those who wish more detailed information about the region.

The material for this pamphlet has been taken largely from the more recent contributions of several groups of workers whose aim was to make a detailed geological survey of the whole quadrangle. Since it seemed best for one writer to correlate the various scientific reports of the area, Katharine Fowler-Billings has written the pamphlet. Marland P. Billings was in charge of the geological mapping of the southern half of the quadrangle, aided by Katharine Fowler-Billings, F. B. Loomis, Jr., W. P. Fuller, Jr., and R. F. Story, all of whom helped during one or more seasons. Richard Goldthwait's work on the physiographic and glacial geology of the Presidential Range is summarized in this pamphlet. His "Geology of the Presidential Range" published by the New Hampshire Academy of Science in 1940 should be consulted by those interested in a more complete description of the development of the Presidential Range by the erosion of streams and the work of glaciers. His booklet is concerned with erosion and glacial geology in the Presidential Range. This pamphlet, on the other hand, deals primarily with the origin and history of the rocks of the whole Mount Washington quadrangle. The geology of the northern half of the quadrangle was mapped by Randolph W. Chapman and Carleton A. Chapman. Exact titles to the reports published by these various workers are found in the bibliography at the end of the pamphlet.

The cost of the geological studies in the Mount Washington quadrangle was partially financed by grants from the Associates in Science of Harvard University and from the Penrose Bequest of the Geological Society of America. The study of the glacial geology of the Presidential Range was financed by the New Hampshire Academy of Science, the Whitney Fund of Harvard University, and the American Association for the Advancement of Science. The printing of the colored geological map was financed by the New Hampshire State Planning and Development Commission and the New Hampshire State Highway Department. Figs. 3 to 10, Fig. 18, and the front cover were drawn by Dr. Erwin Raisz of the Institute of Geographic Exploration at Harvard University.

Geology of the
Mt. Washington Quadrangle
New Hampshire

By Marland P. Billings, Katharine Fowler-Billings, Carleton A. Chapman, Randolph W. Chapman and Richard P. Goldthwait

THE SCENERY

THE MT. WASHINGTON area is one of the most popular vacation centers in New England. The Presidential Range, in the southeastern part of the quadrangle, is dominated by Mt. Washington, which rises to a height of 6288 feet above sea level. These mountains beckon the hiker in summer and the skier in winter (Fig. 1). Excellent trails make

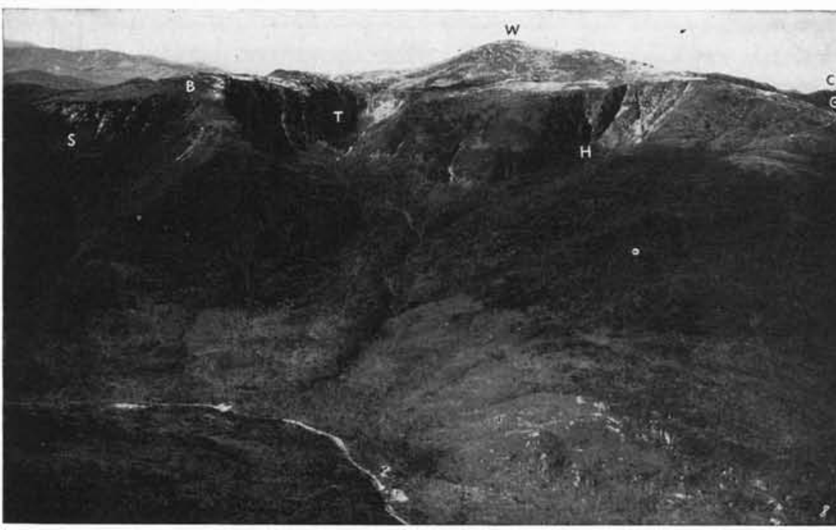


Figure 2 — Aerial view of Mt. Washington from the east. Cone of Mt. Washington — W — rises above the flat Presidential Upland. Cirques formed by local mountain glaciers are: Gulf of Slides — S; Tuckerman Ravine — T; Huntington Ravine — H; Great Gulf — G. Mt. Clay — C — is at the extreme right; Boott Spur — B — lies on the Presidential Upland. (Photo by H. Bradford Washburn, Jr. Courtesy of the Flume Reservation, Franconia Notch, N. H.)

it possible to reach the peaks from the main roads on all sides of the range. The Appalachian Mountain Club maintains camps where the traveler can obtain food and lodging at Pinkham Notch, the Lakes of the Clouds, and west of the summit of Mt. Madison. An auto road on the eastern slopes of Mt. Washington and a cog railroad on the west make it possible for thousands of visitors to reach the highest point in the northeastern United States with no physical effort. A summer hotel has been maintained on the top of Mt. Washington for many years. Daily weather statistics for forecasts are obtained the year round at the Mt. Washington Observatory on the summit. Recently the Yankee Network has built a frequency modulation radio tower and headquarters near the summit, contributing to the ever increasing importance of the mountain top.

The rounded rock-strewn cone of Mt. Washington, rising above the flat upland of the Alpine Garden on the east and Bigelow Lawn on the south (Fig. 2), contrasts with the sharper, steeper summits of the other peaks of the Presidential Range which stretch out to the north and south (Fig. 23). Streams are absent from the rock-strewn slopes above timberline, which in this region is about 4500 feet above sea level. Steep, V-shaped valleys scar the lower forested slopes of the Presidential Range on the west (Fig. 1). Small streams begin their dissection at tree-line, and cascade down the western slopes in a series of waterfalls to join the larger rivers in the broad valleys in the lowlands.

Many of the valleys on the north and east sides of the Presidential Range, in contrast to the V-shaped valleys on the west, head in great bowl-shaped depressions called "cirques" (Fig. 2). These spectacular cliffed depressions once held small mountain glaciers, and are now the catchment basins of large quantities of snow every winter. Tuckerman Ravine, Huntington Ravine, the Great Gulf, and King Ravine are the best known of these basins. The streams which rise in these depressions are swift-flowing, full of cascades and waterfalls.

The dissection on the northern flank of the Presidential Range is similar to that on the east of the range, except that there are fewer cirques. Some of the streams do not rise in the bowl-shaped depressions, but start as rivulets on the mountain slopes, as on the west side of the mountain. Many beautiful waterfalls such as Cold Brook Fall, Tama Fall, and Coösauk Fall are found along the course of these streams.

The whole quadrangle can be viewed from the summit of Mt. Washington. To the west lies the Dartmouth Range, with the summer resort of Bretton Woods nestled in the deep valley of the westward flowing Ammonoosuc River. Far to the west, Cherry Mountain rises, with the flat swampy valley of the westward flowing Israel River on the north. The small villages of Jefferson, Meadows, and Jefferson Highlands lie in this flat valley, north and east of the swampy area. The valley can be followed eastward to Bowman, where it is occupied by the eastward flowing Moose River. Randolph, with its summer cottages and hotels, lies still farther east in this east-west valley. To the north of this valley occupied by the Israel and Moose Rivers are the forested, rather inaccessible Pliny Range, Pilot Range, and Crescent Range. These ranges are less rugged than the Presidential Range, but nevertheless they are tempting to the mountain climber. A closer view would bring out the sweeping, crescent-shaped curve of the Crescent Range, swinging in a broad arc towards the northeast. The Pliny Range, north of Jefferson, also has a broad arc-like shape, turning northwards into Round Mountain, which in turn joins the southward extending Pilot Range.

Between the Crescent Range on the east and the Pliny and Pilot Ranges on the west lies a vast forested area locally known as the "north country." It is a little known region, except to the lumberjack, since it is far from any village, and only the occasional hiker goes into this isolated game region. A rolling valley five miles across, it is drained by the headwaters of the Upper Ammonoosuc River, which in the Percy quadrangle turns westward to join the waters of the Connecticut River at Groveton. The northern part of the Pliny Range and the western slopes of the Pilot Range are dissected by the steep tributaries of Garland Brook which flows westward through Lancaster Township.

It is easy to see why the region stands foremost in the hearts of New Englanders as a vacation center for the nature lover and a haunt of the skier in winter. The variety of scenery is unlimited, and the story which is unfolded in the rocks and mountains is a fascinating one. The following pages reveal the history of the mountains. For vast eons the area was the site of a great inland sea. Later, the deposits that had accumulated in this sea were folded and invaded by great masses of molten rock. Volcanoes periodically added their contribution to the rocks of the region. Still later came the great erosion, during which masses of rocks many thousands of feet thick were removed by patient streams. Finally came the Great Ice Age, when mountain glaciers carved out great amphitheatres on the mountain slopes and the whole region was overwhelmed by an invading ice sheet from Canada.

THE STORY OF THE ROCKS

The Colored Geologic Map

To understand the story of the rocks, the reader must first unfold the colored geologic map at the back of the pamphlet, and get acquainted with the region as a whole. As he looks at the map, he may be impressed by the variety of rock formations in the Mt. Washington quadrangle. Each pattern and color means a different kind of rock with an individual story of its own.

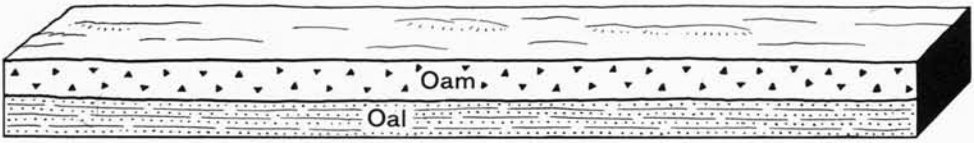
The legend at the edge of the map gives a complete list of all the types of rock in the area, starting from the oldest rocks at the bottom of the right-hand column, to the youngest at the top of the left-hand column. Detailed descriptions of the minerals in each rock formation are printed in small type in the legend. This detail concerns the professional rather than the amateur. Any technical names will be explained simply in the following account of the story of the rocks. The little letters in the boxes of the legend are a second device in addition to the color patterns to aid the reader to find out what particular kind of rock occurs in any locality. The cross sections at the foot of the map are to show what would be found in trenches cut down through the earth to sea level. They should help the reader visualize the rocks in the depths of the earth, while the geologic map simply shows the plan of the rocks. There is a more complete description of how to read the map at the end of the pamphlet.

To help understand the legend of the map a chart summarizing the sequence of events of the region is included in the text on page 14. There is also a series of diagrams, Figs. 3-10, which represent the history of the region from the laying down of the oldest rocks until the coming of the Great Ice Sheet. These cross sections are to aid in understanding how some of the rocks were laid down under water, then folded, and injected by hot molten rock, and finally worn away, producing our present mountains with many rock types exposed at the surface.

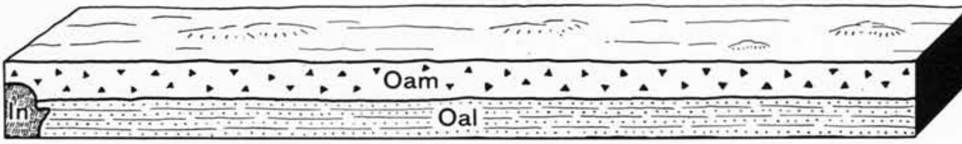
The Great Inland Sea

Our story of the Mt. Washington quadrangle begins about 375 million years ago, when central New Hampshire was covered by a great inland sea. The eastern shore of this sea was far to the east, probably somewhere in the present Gulf of Maine. Still farther to the east lay land, stretching far out into what is now the Atlantic Ocean. Westward flowing streams, constantly attacking this land, continuously carried tiny particles of sand and clay to the inland sea. Although a slow, laborious process, it continued for countless eons, and vast quantities of sand and mud were deposited in the New Hampshire sea.

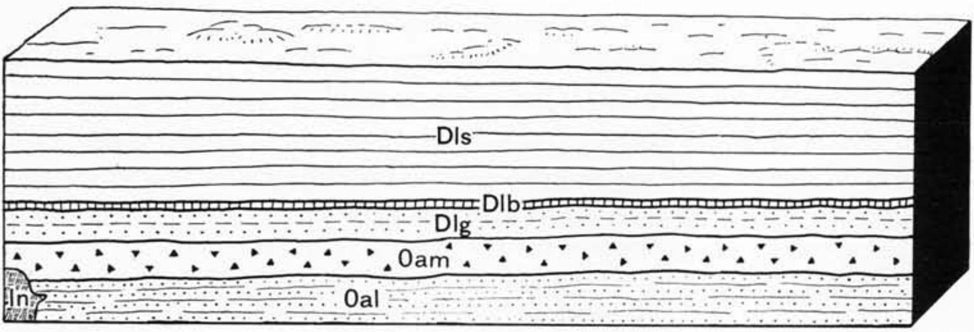
The first deposits of which we have any record in the Mt. Washington quadrangle were composed chiefly of sand. Although the individual layers were only a few inches, or at the most, a few feet thick, eventually a great sheet of sand many thousands of feet thick accumulated. The sea was never very deep, for the bottom gradually sank as the sands were laid down. These deposits, now altered to light-gray to dark-gray quartzites, constitute the Albee formation, which is now exposed only in the northwestern part of the quadrangle. This formation may be seen in a series of outcrops occupying an area 1 mile long and 1000 feet wide 4½ miles north of the village of Jefferson. There are also numerous smaller isolated patches of the Albee formation in the Pilot Range (see geologic map).



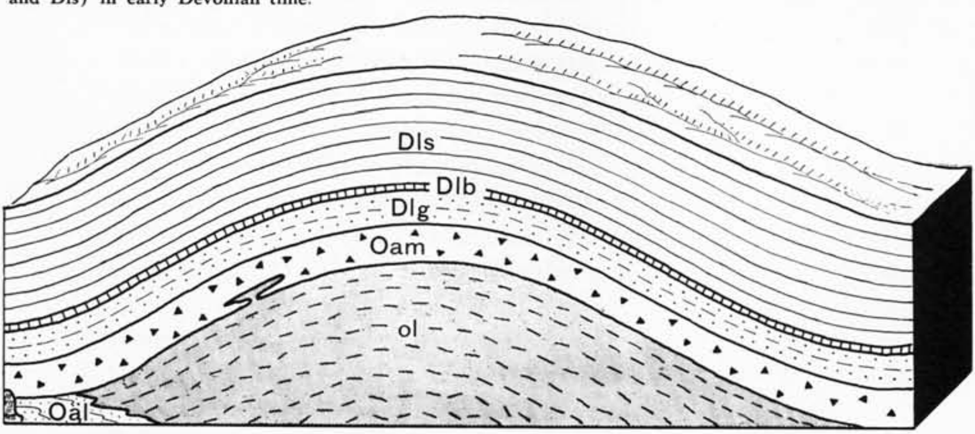
3 — Sands (Oal= Albee formation) and volcanic rocks (Oam= Ammonoosuc volcanics) are deposited, probably in late Ordovician time.



4 — Molten rock invades region and freezes to form Lost Nation group (ln), probably in latest Ordovician time.

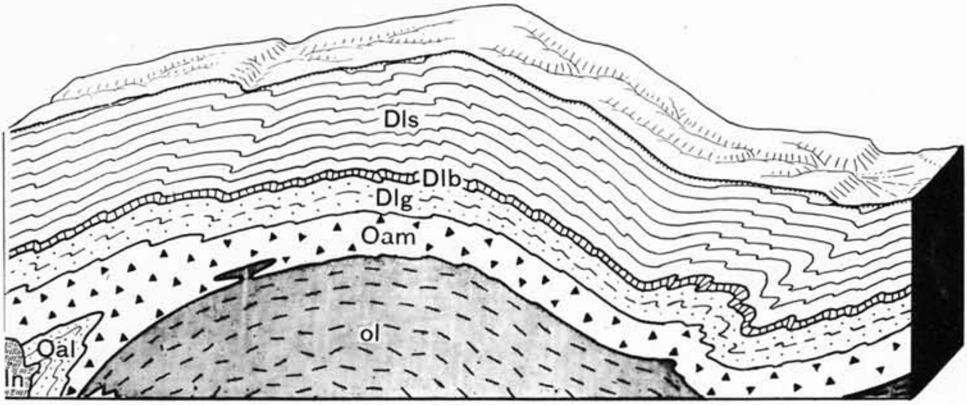


5 — Sand, mud, and a little impure limestone are deposited to form Littleton formation (Dlg, Dlb, and Dls) in early Devonian time.

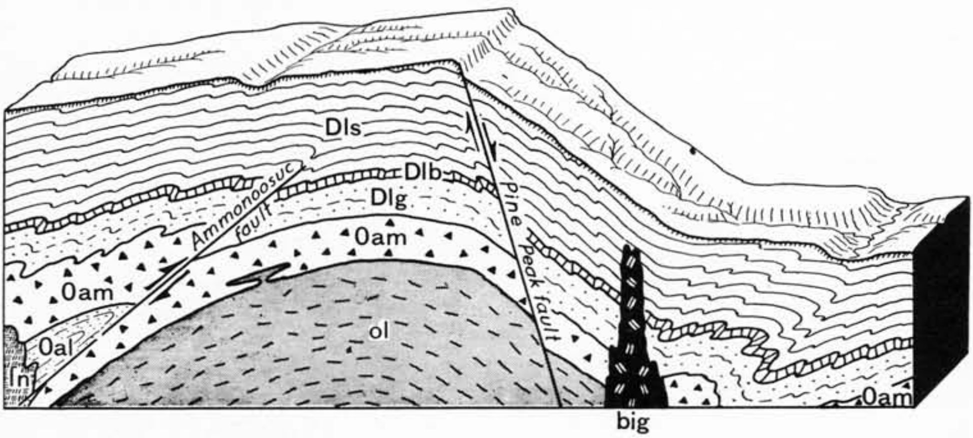


6 — Molten rock pushed in as a great lens-like body freezes to form the Oliverian magma series (ol), probably in middle Devonian time.

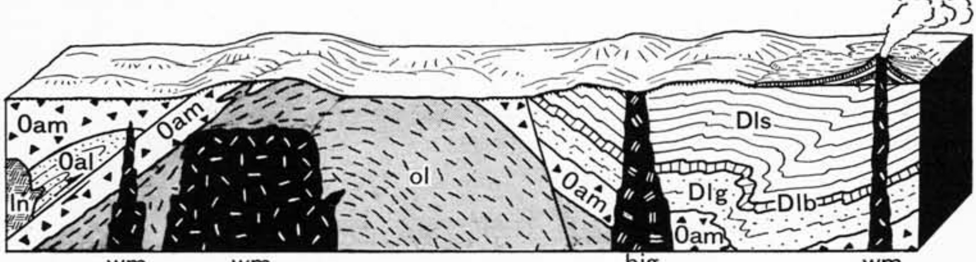
FIGURES 3-10 — Series of diagrams to illustrate the story of the rocks. The cross sections are imaginary trenches a mile or so deep across Mt. Washington quadrangle from northwest to southeast. The sections are necessarily diagrammatic, with some foreshortening. Each section shows a progressive development in the history of the region. Consult the geologic time-scale on p. 14 for a chart of the sequence of events in the region. Oal=Albee formation; Oam=Ammonoosuc volcanics; ln=Lost Nation group of the Highlandcroft magma series; Dlg=gneiss of the Littleton formation; Dlb= Boott member of the Littleton formation; Dls schists and quartzites of the upper part of the Littleton formation; ol= Oliverian magma series; big=Bickford granite of the New Hampshire magma series; wm=White Mountain magma series.



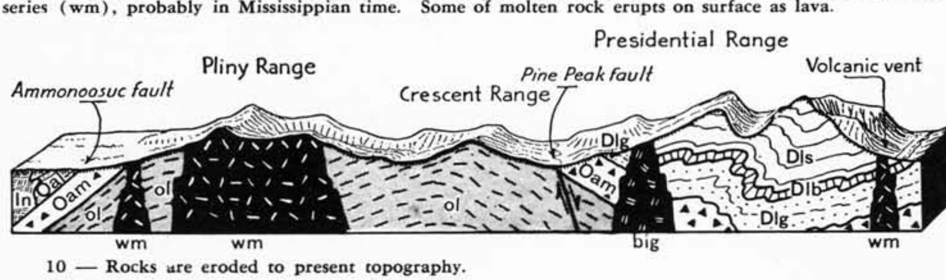
7 — Great folding, probably in late Devonian time.



8 — Invasion by molten rock which freezes to form Bickford granite (big), is followed by faulting, probably in latest Devonian time.



9 — After considerable erosion, more molten rock invades area to form White Mountain magma series (wm), probably in Mississippian time. Some of molten rock erupts on surface as lava.



10 — Rocks are eroded to present topography.

Geologic Time - scale, with sequence of events in the Mount Washington Region

OLDEST EVENT IS AT BOTTOM OF CHART; YOUNGEST IS AT TOP

Era	*Period*	*Time-scale (age of beginning of period)*	*Sequence of geological events.*
Cenozoic	Recent	Thirty thousand years ago.	Slight erosion; frost action.
	Pleistocene	Two million years ago.	Wisconsin stage of the Continental Ice Sheet covered the region, depositing glacial drift, sands and gravels. Local mountain glaciation preceded the coming of the Ice Sheet. Earlier ice sheets probably covered the region, but left no recognized records.
	Tertiary	60 million years ago.	Uplift and renewed erosion. Rocks eroded to the Presidential erosion surface which was not much above sea level, but above which low hills rose.
Mesozoic	Cretaceous	120 million years ago.	Erosion.
	Jurassic	150 million years ago.	Erosion.
	Triassic	175 million years ago.	Erosion.
Paleozoic	Permian	210 million years ago.	Erosion.
	Pennsylvanian	255 million years ago.	Erosion.
	Mississippian	290 million years ago.	White Mountain magma series intruded. Dikes, vents, ring-dikes, large granite and syenite bodies; some lavas.
	Devonian	330 million years ago.	Erosion Faulting New Hampshire magma series intruded. Bickford granite and pegmatites, probably Late Devonian. Folding and recrystallization of the rocks. Oliverian magma series intruded in form of a great dome, probably Middle Devonian. Littleton formation deposited in large inland sea. Early Devonian. Upper part: 4000 feet of mud and sand (now schist and quartzite). Boott member: 0-200 feet, chiefly impure limestone. Lower part: 1400 feet of mud (now a gneiss).
	Silurian	355 million years ago.	Erosion.
	Ordovician	415 million years ago.	Highlandcroft magma series (Lost Nation group) intruded in northwest corner of quadrangle. Ammonoosuc volcanics, 5000 feet thick in places, accumulated. Albee formation, mostly sand (now quartzite) deposited.
	Cambrian	515 million years ago.	No record.
Pre-Cambrian		More than one thousand million years ago.	No record.

A period of intensive volcanic activity followed. The volcanoes lay to the east of the Mt. Washington quadrangle, although nothing remains of the original volcanoes. Vast quantities of volcanic debris were carried westward by the streams. Sometimes deposits of volcanic ash dropped directly from the air, and occasionally lava flows invaded the Mt. Washington region. Eventually the great sheet of volcanic deposits was 5000 feet thick (Fig. 3). It is very probable that throughout most of this time the ancient sea was completely filled up by volcanic debris, so that the streams from the eastern mountains flowed westerly across the Mt. Washington area. These volcanic rocks belong to the Ammonoosuc volcanics. Because of extensive changes during the period of folding to be described on a later page, these volcanic rocks now consist chiefly of fine-grained gray biotite gneiss, but include some mica schist and some layers of a rock called granulite. There are also some black rocks composed of a mineral called hornblende; this rock is called amphibolite.

The Ammonoosuc volcanics occur along the lower slopes of the northern flank of the Presidential Range in a belt almost one and one-half miles wide. They are well exposed in places along the Israel River, The Mystic, Cold Brook, and Snyder Brook. There are a few other poorer exposures east of Randolph and northwest of the Dartmouth Range. The Ammonoosuc volcanics also crop out in Lancaster township (see geologic map).

The volcanic activity ceased, and the sea temporarily withdrew from New Hampshire. Molten rock, called magma, rose from the depths of the earth and invaded the Albee and Ammonoosuc formations (left-hand end of Fig. 4). This magma froze beneath the surface to form dark-colored granitic rocks, which, known as the Lost Nation group, are exposed in the northwest corner of the quadrangle (see geologic map). For millions of years after this invasion of molten rock the Mt. Washington quadrangle continued to be dry land.

About 330 million years ago, in early Devonian time, widespread seas again covered most of New Hampshire. Thousands of feet of alternating layers of mud, sand, and a little impure limestone were laid down (Fig. 5). The accumulation of all these deposits took many hundreds of thousand years. The whole of the Presidential Range is made up of deposits laid down in this great inland sea. The seas extended even further south than Mt. Monadnock, and near Littleton and Mt. Moosilauke fossils of marine animals of Devonian age have been found. All of the rocks in New Hampshire which were laid down in this great inland sea in early Devonian time have been named the Littleton formation. Although no fossils have yet been found in the Presidential Range, someone may discover remains of former life if a careful search is made. Although greatly altered by folding, heat, and pressure during the millions of years since they were first laid down, the original layers of mud and sand, now changed to gneiss, schist, and quartzite, can easily be recognized almost anywhere in the Presidential Range. One of the very best places to see these layers is along the Auto Road on Mt. Washington between the 5 and 6-mile posts (Fig. 13).

The Littleton formation consists of three distinct units,

Figure 11 — Typical black and white banded gneiss of the lower member of the Littleton formation. (This photo by R. F. Story was taken along the Peabody River just east of the Mt. Washington quadrangle in the Gorham quadrangle.)

as can be seen by studying the geologic map. Originally sand and mud, the lower part of the formation is now chiefly a black and white banded gneiss with alternating layers averaging an inch in width (Fig. 11). The dark layers are chiefly black and white mica, with some quartz and feldspar. The light layers are chiefly quartz and feldspar, looking like granite. Locally the gneiss is cut by numerous vein-like bodies of granite. The lower part of the Littleton formation, overlying the Ammonoosuc volcanics, occupies two areas, one of which extends northeasterly from Mt. Deception through Bowman to the northeast corner of the map. The second area, forming a great semicircle, may be traced from Pinkham Notch westward to Mt. Franklin and northwesterly to Millen Hill. Good exposures may be seen in many places, especially on the summits of Mt. Clay and Mt. Monroe.

Figure 12 — Typical thin-bedded limy rocks of the Boott member of the Littleton formation. (This photo by R. F. Story was taken along the West Branch of the Peabody River just east of the Mt. Washington quadrangle in the Gorham quadrangle.)

A thin, but persistent belt of rocks, called the "Boott member," is one of the beds that has aided in solving the complicated structure and folding of the rocks of the Presidential Range. This formation separates the lower and upper beds of the Littleton formation, and was laid down in the Littleton seas as a thin layer of impure limestone on top of the muds and sands in the lower part of the formation. The limestone has now been changed to hard, compact rocks, composed of dark and greenish grains of diopside and needles of actinolite. Interbedded with these rocks are black micaceous layers, some of which contain pyrite. The formation, when once recognized, is very distinctive (Fig. 12). Unusually good and accessible localities to see this formation are: (1) Cutler River, 2170 feet, between the Appalachian Mountain Club bridge and the foot of Crystal Cascade; (2) pass 1000 feet northeast of the summit of Mt. Monroe; (3) headwall of Oakes Gulf; and (4) between altitudes of 1620 and 1635 feet on the West Branch

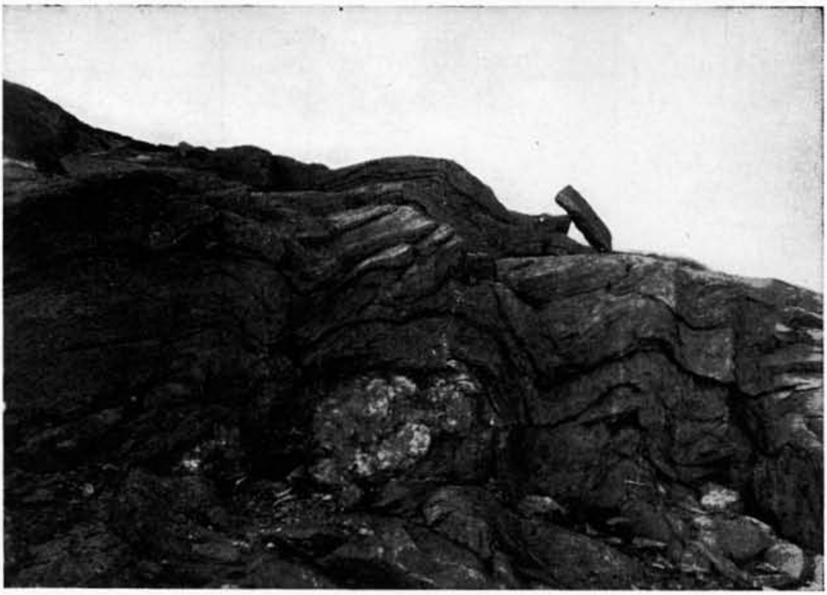


Figure 13 — Folds in the schists of the upper member of the Littleton formation between the 5 and 6-mile posts of the Mt. Washington Auto Road. Cliff face is about 12 feet high. The rock splits along foliation planes which are well developed parallel to the bedding. (Photo by G. Shorey.)

Figure 14 — Crystals of sillimanite etched out by weathering. The sillimanite has recrystallized largely to mica and quartz. (Photo by K. F. Billings taken along the Auto Road at about 4000 feet elevation.)

of the Peabody River, in the Gorham quadrangle. It is absent on the northern slopes of Mt. Adams and Mt. Madison.

The upper part of the Littleton formation makes up the bulk of the bedrock on most of the higher summits on the Presidential Range. Originally sand and mud, it now consists of interbedded quartzite and mica schist, the latter containing sillimanite, staurolite, garnet, black tourmaline, and mica (Figs. 13, 14, 15, and 16). Since the schists of the upper part of the Littleton formation differ greatly from place to place, each exposure must be examined separately for individual minerals. Excellent exposures may be seen: (1) along the Mt. Washington Auto Road; (2) summit of Mt. Madison; (3) Tuckerman Ravine; (4) Huntington Ravine; (5) passes north and south of Mt. Jefferson.

Intrusion of the Oliverian Magma Series

In middle Devonian time, some 310 million years ago, great disturbances within the depths of the earth began to be felt in the Mt. Washington region. Molten rock was pushed up beneath the overlying beds and formed a great dome that extended across the central and northern parts of the Mt. Washington quadrangle (Fig. 6). These intrusives are a series of coarse granite-like rocks of slightly varying composition. They cooled slowly far beneath the present surface. These rocks belong to the so-called Oliverian magma series, and are shown on the colored geologic map in green patterns. They were thrust up under and into the already hardened older rocks.

Folding of the Rocks

During middle, or late Devonian time, some 300 million years ago, this part of New Hampshire went through a period of intense folding. The rocks, squeezed as in a great vise, became plastic due to the great heat and pressures accompanying the paroxysms. The shales and sandstone layers were thrown into a series of folds (Fig. 7), and the original minerals of the rocks began to change under the new temperature-pressure conditions, so that the sandstones and shales gradually became gneiss, schist, and quartzite. Mt. Washington itself is a part of one of these great warps in the earth's crust formed at this time, with countless smaller folds superimposed upon the larger folds (see cross section CC′ at the bottom of the colored geological map).

Figure 15 — Slightly folded quartzite (light) and mica schist layers of the upper part of the Littleton formation. (Photo by W. P. Fuller, Jr., taken on Dome Rock.)

Figure 16 — Folded quartzite (light) and mica schist layers of the upper part of the Littleton formation. (Photo by W. P. Fuller, Jr., taken on Dome Rock.)

The folded rocks may be seen in many places in the Presidential Range. The folds are most easily recognized where there are alternating layers of quartzite and schist that range in thickness from a few inches to a few feet (Figs. 15 and 16). In some places a large fold many feet across is found. Again, small folds a few inches across, or wrinkles in the schist so small they can scarcely be seen by the naked eye, can be detected.

One of the most accessible places to see this folding is along the Auto Road on Mt. Washington between the 5 and 6-mile posts (Fig. 13). The Nelson Crag trail in this same vicinity follows along approximately the same bed, which descends eastward in a series of rolls, like a sheet of corrugated iron sloping to the east. On the southeast side of John Quincy Adams a rather dramatic fold 30 feet high lying on its side can be seen with little difficulty, if one stands facing the mountain top (Fig. 17). Mt. Madison is also made up of similar folds, which are imposed on a still larger folded structure; the folds are well exposed on the upper 300 feet of the mountain.

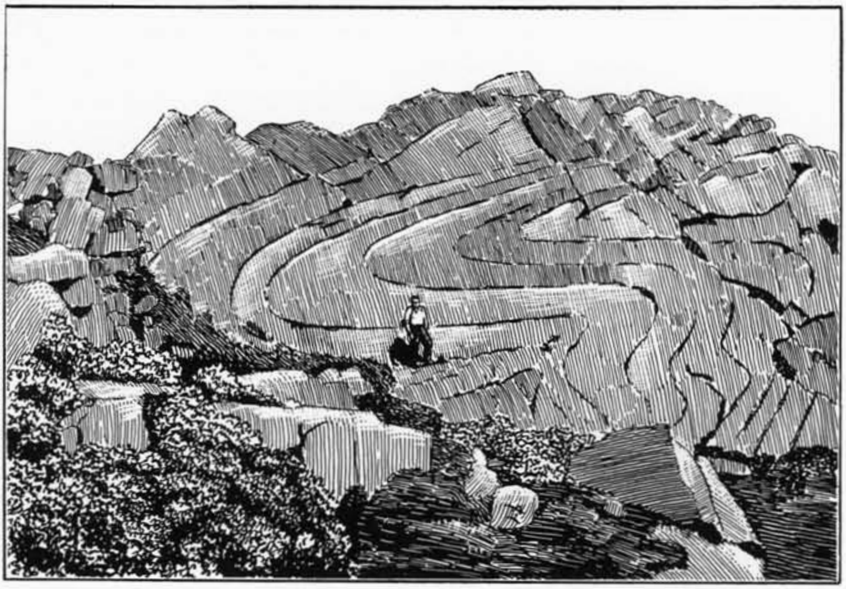


Figure 17 — Folded schists of the Littleton formation on southeast face of John Quincy Adams. (Drawing by Ed. Schmitz from photo.)

Locally, where the layers are rather thin, beds of the Littleton formation look as if they had been twisted and folded like putty. One of the most accessible localities to see this phenomenon is about 1½ miles due south of Randolph on the north end of Gordon Ridge along the trail which extends westerly from the 2740′ knob. This point is locally known as "Dome Rock," and the trail along which the exposures are so excellent is called the "Inlook Trail" on the Appalachian Mountain Club map of the Mount Washington Range (Figs. 15 and 16).

In studying the details of the folds, the trend (strike) of the bedding, along with its inclination (dip) should be observed. Appropriate symbols contained in the legend accompanying the geologic map indicate the attitude of the bedding at numerous places in the area. (See section entitled "How to Read the Map" at end of pamphlet.)

Other structures, which might be confused with bedding, are joints and foliation (Fig. 18). Joints refer to the many smooth open cracks along which all rocks split when exposed to surface conditions. Jointing usually causes the rock to split into rectangular blocks. The loose talus blocks littering the upper parts of the mountains have been split from the bedrock by ice freezing in the joints, expanding, and finally causing the rocks to split off. The summit of Mt. Washington is a mass of these talus blocks, and true bedrock is difficult to find, so thoroughly has frost action done its work. The headwalls of the ravines are fine places to study joints (Figs. 19 and 20). Also, most of the waterfalls cascade down over well jointed rock (Fig. 30).

Foliation refers to the property of a rock to split along parallel planes. One type of foliation is due to tiny parallel

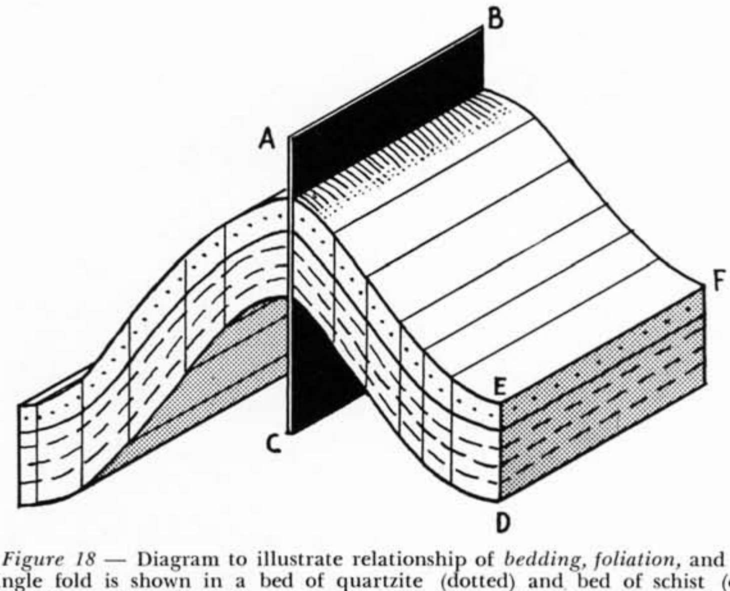


Figure 18 — Diagram to illustrate relationship of *bedding, foliation,* and *joints.* A single fold is shown in a bed of quartzite (dotted) and bed of schist (dashed lines). The *bedding* is the layering. The plane ABC through the crest of the fold dividing it as symmetrically as possible is called the "axial plane." *Foliation planes* are parallel to the axial plane and cut right across the bedding (DEF is a foliation plane). There are also foliation planes in the schist (dashed lines) parallel to the bedding. *Joints* are any smooth fractures in the rocks, either parallel to the foliation, or at an angle to the bedding.

plates of mica and flattened grains of other minerals, such as quartz and feldspar. This type of foliation is generally parallel to the bedding, and was developed by the squeezing of the beds when they were compressed and folded, causing the minerals to line up along the path of least resistance. As a result, the rocks split readily along these planes, leaving shiny micaceous surfaces (Fig. 16). Foliation is especially prominent on all the higher peaks. A second type of foliation is caused by closely spaced parallel fractures.

The cone of Mt. Madison is a good place to study bedding, jointing, folding, and foliation (Fig. 18). In fact, in most

Figure 19 — Black dike in Huntington Ravine, showing characteristic blocky jointing which is more easily eroded than the coarsely jointed Littleton formation into which it was intruded. (Photo by G. Shorey.)

Figure 20 — Headwall of Huntington Ravine showing gully (in middle distance) formed by dike which is easily broken down by erosion due to its many joints. (Photo by G. Shorey.)

localities above tree line where the rocks are well exposed, many of these structures can be recognized with little difficulty.

The Formation of New Minerals

While the folding was going on, and even after it had been completed, new minerals were being formed in the rocks. The changing pressure and temperature conditions caused different minerals to form at different times. A mineral which is stable at one temperature may be unstable at a higher or lower temperature, and is replaced by another mineral. Thus, andalusite developed in the schists of the Littleton formation at one time. Then, as the heat and pressure increased, it became unstable and was replaced by a white bladed mineral called sillimanite. In many places the sillimanite is only a "ghost" of its former self, white mica having partially or wholly replaced it, the original outline of the sillimanite still being retained (Fig. 14).

Red garnets, black tourmaline, and dark brown staurolite are minerals which developed in general after the folding had been completed, for they cut across the folded structures. Mica is the commonest of all the minerals, for it is everywhere in the schists.

In general, the recrystallization of the rocks went on without much additional material seeping up from the depths. There was merely a reorganization of the materials already present. Locally, a little soda and potash were introduced. The Ammonoosuc volcanics were entirely recrystallized, so that they do not in the least resemble their original mineral composition. In the lower part of the Littleton formation the temperature conditions were such that the rocks became partially liquified in places, and a gneiss developed, with the lighter bands closely resembling granite. A complete reorganization of the original materials occurred so that there was a segregation of the lighter materials, resulting in a black and white banded rock which is much contorted in places (Fig. 11). The Boott member of the Littleton formation completely changed its original character, actinolite and grains of diopside developing in some of the more limy layers.

The upper part of the Littleton formation became tough, compact quartzites and garnet-mica-sillimanite schists, which now hold up the higher peaks of the Presidential Range. They are among the most compact and resistant rocks in New England; not only Mt. Washington, and the other peaks of the Presidential Range, but also Mt. Moosilauke, Mt. Stinson, Mt. Carr, Mt. Kearsarge, and Mt. Monadnock, are all made up of these recrystallized, folded schists and quartzites of the Littleton formation.

Finally, the folded and squeezed rocks of the Littleton formation with the new minerals developed by recrystallization, were much as they appear today, but they were still far below the surface of the earth. However, the invasion of igneous magma from the depths of the earth was not over, although the folding and recrystallization period was completed. There were still to be many injections of molten rock into this part of New Hampshire.

Intrusion of the New Hampshire Magma Series

A fine-grained gray granite of the New Hampshire magma series was intruded after the folding of the rocks of the Mt. Washington region (Fig. 8). This granite came in during late Devonian time, and is called the Bickford granite. It is fresh looking and unfolded, cutting across the structure of the older rocks, indicating its intrusion after the compressive forces had ceased. The largest body extends from Bretton Woods to Castle Brook. A smaller body extends from Cold Brook to east of Randolph Station (see geologic map). Pematites are associated with this granite. These are coarse, granite-like bodies of varying width which cut across the other rocks in vein-like masses. They were formed when hot fluids were forced out of the larger body of granite as it cooled. Feldspar, quartz, mica, and black tourmaline are the most conspicuous minerals found in these pegmatites. Sometimes veins of pure white quartz worked their way up into the openings in the rocks (Fig. 24).

Faulting

The long black line on the geologic map running from Fabyan northeast through Pine Mountain (Pine Peak on the

Appalachian Mountain Club map), Bowman, and Randolph, marks a great dislocation (fault) in the earth's crust. This great break, called the Pine Peak fault, occurred some time after the intrusion of the Bickford granite at the very end of Devonian time and caused the offsetting of the rock formations along its length (Fig. 8). The northern part of the area moved up in relation to the southern half of the region. Solutions deposited silica in the rocks near the crack in some places. Pine Peak in the Dartmouth Range is a mass of this silicified material. The shiny white outcrops at the top of the mountain are conspicuous even from the Presidential Range.

Another large fracture that formed at this time is the Ammonoosuc fault, exposed in the northwest corner of the quadrangle near Bunnell Brook.

Intrusion of the White Mountain Magma Series

The last phase of the welling up of molten magma from the depths of the earth, bringing into the area a variety of granites and dark-colored igneous rocks, occurred about 275 million years ago, probably in Mississippian time. The rocks which came in at this time belong to what is known as the White Mountain magma series, and are found principally in the northern part of the area in ring-like structures, or circular bodies, and in dikes cross-cutting the other rocks (Fig. 9). The Cherry Mountain syenite—a coarse granite-like rock—and the granites of the Mt. Oscar region worked their way into the rocks at this time.

In the Pliny Range, Pilot Range, and Crescent Range, the White Mountain magma series came into circular cracks in the earth's crust, forming what are known as "ring-dikes." A study of the geologic map will show the arc-like pattern of many of these intrusives. The Crescent Range and the Pliny Range are striking examples of these rings, the topography itself being controlled by the circular pattern of the intrusives. Because they are harder than the surrounding rocks, they hold up the higher peaks. There are various theories offered to explain the curved fractures in the earth into which the ring-dikes were intruded. Possibly there was a settling of the crust in this region, resulting in a series of concentric fractures. Pressures pushing up from below could account equally well for such fractures. Curved fractures can be made in ice by throwing a rock into an ice-covered pond. Water moves up into the cracks and central hole much as molten magma might move up into curved fractures in the earth's crust.

The material making up the various ring-dikes and central stock-like mass of the Pilot Range varies slightly in each of the separate intrusives. This is because the molten magma in the earth is not uniform, and each ring-dike or large intrusive body came in at a slightly different time, forming rocks of different composition. This accounts for the variety of names of the intrusives of the White Mountain magma series, for each rock type has a slightly different mineral content (see legend of geologic map). The Crescent Range ring-dike probably came from a slightly different center than the Pliny Range ring-dike.

Although there are no ring-dikes in the Presidential Range and southern part of the Mt. Washington area, there are numerous small, dark-colored dikes which came in at about the same time. These were intruded in small straight fractures in the rocks (Figs. 19 and 20). Some of the dark-green dikes are full of mica and sheared. These came in at a much earlier date. They were never molten magma, but were plastic rock derived from the Boott member of the Littleton formation. Some of the material making up the limy layers became plastic as the rocks were folded, and worked its way up into cracks of the Littleton formation. The plastic material hardened in the rocks just as magma, the resulting dike-like bodies being very difficult to distinguish from dikes derived from molten magma. The Tuckerman Ravine Trail follows one of these dikes for 400 feet near the upper part of the headwall of the Ravine.

Volcanic vents, or throats of volcanoes which existed during late Mississippian time, are found to the west and north of Pinkham Notch (see map for location). They can be recognized by the presence of large angular blocks embedded in a dark-colored rock. Any lava flows which may have poured out of these volcanoes have long since been worn away in this region (Fig. 9).

The Wearing Down of the Land

The formation of the bed rock was now complete. But this is only part of the story. All rocks are subject to erosion as soon as they rise above sea level. Masses of rock thousands of feet thick had to be worn away by streams before the region even began to have its present aspect. As the rocks of the Littleton formation were folded and crumpled, overlying rocks which have long since disappeared were being broken down by ever active streams, and carried piece by piece to the distant seas. Figures 6, 7, and 8 are over-simplified insofar as they neglect this contemporaneous erosion. As erosion progressed there was a gradual rise of land in the area, and the ancient mountains may never have been much higher than the present ones. As the land rose, the streams cut deeper. until even the granites which had been intruded far below the surface of the earth were finally exposed (Fig. 9).

After many millions of years of this attack by the streams, the area became a rolling plain surmounted by hills a few hundred feet high. This plain may be called the Presidential erosion surface or, for brevity, the Presidential upland. Such a plain is suggested by the flat surfaces high up near the present mountain summits. Instead of the ruggedness of the lower slopes, there are great flat stretches on the shoulders of the higher peaks. The Alpine Garden and Bigelow Lawn on the slopes below the cone of Mt. Washington are well known to the hiker (Fig. 2). These flat stretches are a pleasant relief after the strenuous headwall climbs, and afford excellent unobstructed views in all directions, since they are above timberline. The Gulfside Trail takes advantage of this upland surface, following it for many miles. It does not take much imagination to fill in the intervening valleys, and think of the whole region as low and rolling before it was raised to its present 5000-foot altitude.

The relief of the Presidential and Pliny Ranges as we view them today is due to a geologically rapid uplift of the whole area, taking more than a million years, perhaps, and causing the streams to cut deeply into the region. The Ammonoosuc River, Israel River, Moose River, and Upper Ammonoosuc

River cut rapidly, widening and deepening their valleys. These main rivers were cutting into granitic rocks which were more easily broken down than the tough schists of the Presidential Range. The peaks of the Presidential Range were destined from the beginning to remain the highest part of the area. They are composed of the toughest rocks of the region, for they are made up of the highly folded, recrystallized schists of the Littleton formation. The sillimanite-mica schists and compact quartzites of which they are composed are broken down very slowly by the forces of erosion. Their folded structure makes them even more difficult to attack than a uniform rock such as granite. While the area was being elevated, the peaks of the Presidential Range retained their form as rounded hills rising above the Presidential upland. Tributary streams developed rapidly on the valley sides, cutting steep V-shaped valleys in the lower slopes (Fig. 1). Waterfalls developed along the courses, as the streams cascaded down into the broad valleys. Gradually the region looked much as it is today (Fig. 10).

North of the Presidential Range, erosion progressed more rapidly. But even here the resistance of the granites in the ring-dikes controlled the final landscape. The Crescent Range took on its graceful sweeping arcuate shape due to the tougher nature of the granite ring of which it is composed. The same is true of the curved shape of the Pliny Range. The deepest valleys developed in the softer granitic rocks of the Oliverian magma series. The Pilot Range stands out, controlled by a tougher granite which was not easily eroded. To the south, Cherry Mountain stands high, because the syenite of which it is composed is tougher than the surrounding granitic rocks. The Dartmouth Range stands higher than the granites which surround it because it is composed of gneisses of the Littleton formation. These gneisses, though not as tough as the schists and quartzites of the Presidential Range, are far more resistant than granite.

It is easy to see, by studying the topography, together with the structure and composition of the rocks of the Mt. Washington region, how the mountains and major valleys are controlled by the toughness of the rocks themselves, as well as the structure. There is a reason for the deeper valleys, the crescent-shaped mountains, and the position of the V-shaped tributary valleys which are carving the higher peaks.

The Great Ice Age

Finally, when the topography of the Mt. Washington region resembled closely that of today, changes in the climate began to be felt. The snowfall became greater, and the mountains remained white throughout the year. This heralded the coming of the Ice Age, which was to give a final molding to the land, modifying the stream-cut surface to some extent. With the increasing cold, little mountain glaciers formed high up in the headwaters on the south, east, and northern slopes of the Presidential Range. These mountain glaciers grew larger, widening the valley heads where they formed. Water freezing in cracks would push blocks of rock out into the ice, which then carried the rock away. Small glacial tongues flowed down the mountain sides, widening the valleys. The spectacular ravines of Tuckerman Ravine, Huntington Ravine, the Great Gulf, King Ravine, and Jefferson Ravine were excavated in this way. Their ampitheater-like forms are called "cirques" (Figs. 2, 21, 22, and 23). They contrast sharply with the steep V-shaped

Figure 21 — Bowl-shaped cirque of King Ravine from Randolph, N. H., Mount Adams is the right-hand peak. The cirque floor is filled by a rock-glacier. (Photo by G. Shorey.)

Figure 22 — Bowl-shaped cirque of Tuckerman Ravine. Excellent exposures of the Boott member of the Littleton formation can be found at the base of the cliffs in the middle part of the foreground to left of the "little headwall." The cone of Mt. Washington rises on the right from the level Presidential Upland. (Photo by G. Shorey.)

canyon heads on the west of Mt. Washington, where the mountain glaciers did not form. The accumulation of snow was less on the west side of the Presidential Range due to the prevailing southwesterly winds which blew the snow over the mountains to accumulate on the east and northern slopes. The prevailing westerly winds of today are a boon to the spring skier who depends upon the great depths of snow that are swept over Mt. Washington to pile up in the cirque of Tuckerman Ravine, making a supply of snow which lasts late into the spring.

Finally, perhaps 50,000 years ago, a great ice cap began collecting in Canada. Gradually this sea of ice moved southward, engulfing mountains and valleys in its path. The ice sheet spread south over all of New England until it reached Long Island. It was a mass of ice many thousands of feet thick, and wherever it passed, it scraped away soil, and moved boulders weighing tons. The rock ledges of the earth were scoured, the hills were rounded, and the valleys deepened by the action of this body of ice.

In north-central United States four glacial stages, involving the formation, advance, and retreat of tremendous ice fields, have been recognized. The glacial stages were separated from each other by periods warmer than the climate of today. In the Mount Washington region there is no known evidence of more than one glacial stage, but undoubtedly glaciation occurred here during all or several of the stages. The records seen here correspond to those of the last of the four glacial stages, known as the "Wisconsin stage." The Wisconsin glaciation lasted about 50,000 years. In New England we have clear proof that the Ice Sheet started melting away from this region about 30,000 years ago. As the ice front gradually retreated by slow melting, lakes formed in many dammed up river valleys. The Connecticut River valley contained some of the best examples of these temporary lakes. The deposits laid down on the bottom of these lakes give a year by year measurement of the retreat of the ice sheet. Other proofs of the recency of the glaciation in New England are found in the fact that the deposits laid down by the ice sheet have undergone little oxidation, stain, or rotting, and only slight erosion.

Figure 23 — Aerial view of The Presidential Range. Tuckerman Ravine is the cirque in the foreground, with the foreshortened summit of Mt. Washington above the headwall. The peaks on the horizon are, from left to right: Mt. Jefferson, Mt. Adams, and Mt. Madison. The bowl-shaped cirque to the right of Tuckerman Ravine is Huntington Ravine. The great gully in the headwall is caused by a black dike which has weathered away more rapidly than the surrounding rocks. (Photo by Army Air Forces. Negative loaned by G. Shorey.)

In New England the continental ice sheet was so thick that even the summit of Mt. Washington was covered. Boulders of gray Bickford granite and pink Oliverian granite, which are called "erratics," and were derived from the solid ledges of the Randolph Valley to the north, have been found near the summit of Mt. Washington as proof of the power of the ice to pick up and move rock in its path. Pockets of till—a clay-like soil with angular fragments of rock brought from a distance—have been discovered in excavations for the buildings on the top of Mt. Washington as further evidence that the ice sheet covered the summit.

Glacial erratics can be found on many of the higher peaks, especially on the north and west sides of the mountains. Mt. Jefferson has many pink Oliverian granite blocks on its northern and western slopes; the absence of erratics on the southeast side is due to a possible protecting zone of stagnant ice on the lee side of the advancing ice sheet.

In places, the ice sheet scoured the rocks over which it passed until they were polished (Fig. 24). Glacial scratches, called striae and gouges, were made by boulders dragged along in the bottom of the ice. These striae trend in a northwest to southeast direction in this area, showing that the ice moved from northwest to southeast. On the cirque walls of Tuckerman Ravine, Jefferson Ravine, Oakes Gulf, and the Great Gulf, there are rounded rock knobs, grooves, and scratches, parallel to the direction of movement of the continental ice sheet. These striae could not have been made by the valley glaciers, since they are at angles to the direction of flow of the valley glaciers, thus proving that the cirques were here before the great continental ice sheet passed.

As the ice sheet melted, deposits of glacial drift were left to cover the rocks in many places. Some of the valleys were filled with sand and gravel laid down by the melting waters of the ice sheet. Old river channels were broadened by the great streams which formed from the melt-waters of the ice.

Figure 24 — Mt. Washington as seen across the Great Gulf from the "Parapet." Cone of Mt. Adams rises on right, with Star Lake in middle distance. White rock in foreground is a vein of quartz which has been smoothed and striated by the Continental Ice Sheet. Other *"roches moutonnées"* rock surfaces in distance were rounded by the ice passing over them from right to left. (Photo by G. Shorey.)

In many places new stream channels were formed as the ice sheet melted. These were used temporarily until lower courses could be resumed as the ice melted from the present valleys. Abandoned river channels may be found today in Jefferson Highlands running almost horizontally along the hillsides, marking the former course of the melt-waters along the frayed edge of the ice sheet. The waters in this region were forced to escape to the south or east, regardless of the present course of the streams, while the hills to the north were still covered by ice. Thus many of the drainage lines had different courses during this period of melting. Small cylindrical potholes on the Ridge of Caps Trail half way up the side of Mt. Jefferson indicate that even at high altitudes large streams existed temporarily as the summits were freed of the ice, while the valleys were still filled.

Hummocky and ridge-like sand and gravel deposits are common above the present valley floors. These were laid down by the streams of the melting ice sheet. The block strewn mounds of sand in the fields northeast of Randolph station are ice contact deposits. Eskers—narrow serpentine ridges of sand and gravel—are found along Deception Brook near Bretton Woods. They mark the position of former stream channels in the ice. Abandoned channels and stream outlets are found in various places. An excellent example of an abandoned stream channel can be seen one-half mile due west of Boy Mtn. north of the highway. In fact, delta-like deposits in temporary ice-ponded waters are found high above the present valley floor in this vicinity. A fine example is the wooded apron of gravel at 1300 feet elevation one mile southeast of Jefferson station. All of these features, left as the ice sheet slowly melted, are interesting remnants that mark the melting of the great ice sheet. The sand and gravel deposits in the valleys are invaluable in building highways, for they make excellent road material.

Post-Glacial Erosion

Since the melting of the continental ice sheet, frost action above timberline on the higher peaks of the Presidential Range has all but obliterated the signs of glaciation. Great blocks have been split off from the bed-rock by freezing and thawing of water in cracks, thus destroying many of the glacial gouges and scratches. In many places above timberline one may readily see that the broken blocks have assumed definite patterns. The blocks move outward and downward due to frost action. On relatively gentle slopes, less than 3°, the blocks arrange themselves into block nets (Fig. 25). Between the blocks in such nets are areas of open fine soil matter with grass. On slopes of 3° to 7° the nets form long block strips (Fig. 26). On still steeper slopes the pattern is that of horseshoe-shaped lobes (Fig. 27). In places a whole succession of these lobes rise above one another to produce distinct terrace effect. Such a relationship is well exposed on the northwest slopes of Mt. Jefferson.

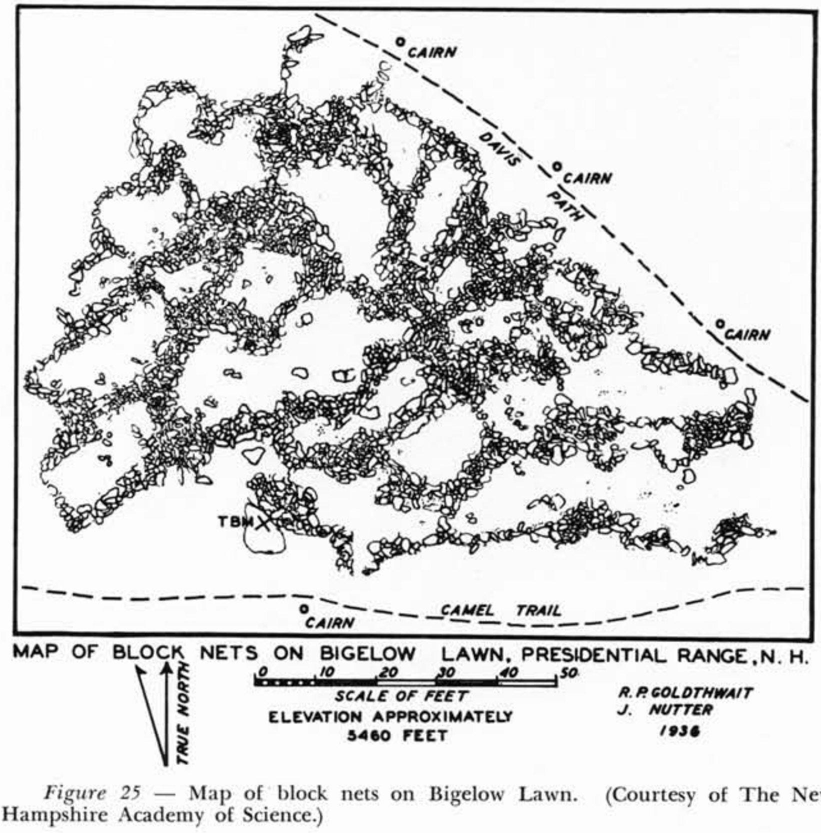


Figure 25 — Map of block nets on Bigelow Lawn. (Courtesy of The New Hampshire Academy of Science.)

Figure 26 — Map of block stripes on Bigelow Lawn. (Courtesy of The New Hampshire Academy of Science.)

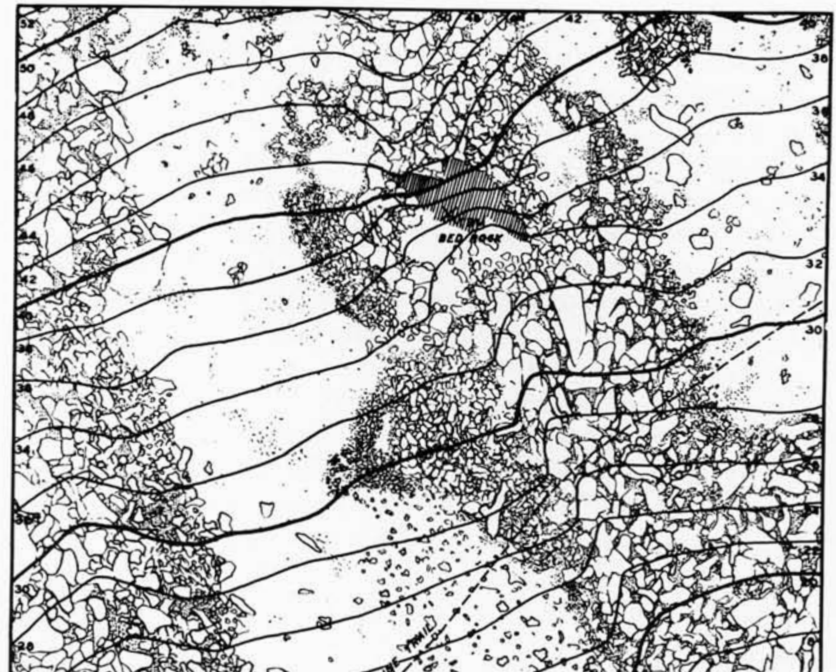


Figure 27 — Map of block lobe northwest of Mt. J. Q. Adams. (Courtesy of The New Hampshire Academy of Science.)

Frost action was more intense immediately following glaciation than it is today. The larger block nets, block stripes, and block lobes were formed then. The mesh of the nets produced then range from 3 to 20 feet in diameter (Fig. 25). Similarly the block stripes and block lobes formed at that time range from 5 to 50 feet in width . Similar forms are developing today, but they are much smaller and are composed of smaller stones. The nets are 3 to 10 inches in diameter.

Many of the cirques are gradually filling up with debris, making it difficult for the hiker to pick his way across the former smooth floors. King Ravine, Huntington Ravine, and the Great Gulf are littered with massive rock fragments, making progress off the trails slow and tedious. The great talus cones which slope about 30 degrees down from the horizontal, have partially filled up the cirques; these cones were largely built during the closing period of the ice age when frost action was far more intense than now. In King Ravine (Fig. 21) a "rock glacier" over half a mile long and nearly a quarter of a mile wide is the result of great blocks that descended from the headwall.

Sharp gullies have formed on the lower till-covered slopes of Mt. Washington as the streams cut into the debris left by the ice. Landslides, sweeping away the thin soil from the steep slopes in flood time, help bring debris downward. The larger streams of the region have re-established their courses on the sand-filled valley floors, only to encounter hard rock surfaces beneath the gravels when their courses are not across the original channels. Many rapids and waterfalls arise in this way, impeding the down-cutting and widening of the channels of the present-day streams.

Thus the frost action of today, together with the ceaseless erosion of the streams, is continuing the slow process of wearing away the land.

INTERESTING LOCALITIES

Cone of Mt. Washington is made up largely of a great mass of jumbled blocks of talus split off from bedrock by frost action. A few obscure ledges of the schists of the Littleton formation can be found. The view of the surrounding country extends in all directions, as Mt. Washington is the highest point in New England. The flat upland surface (Presidential Upland) below the cone at about 5000 feet altitude shows up well from the summit, with the steep drop-off starting at timberline, which is at about 4500 feet.

Lakes of the Clouds lie on the upland surface, below the cone of Mt. Washington. They are small basins excavated in the rocks by the action of the Continental Ice Sheet. The nearby ledges of bedded quartzite and schist of the Littleton formation have been well rounded by the scouring action of the ice sheet. Due south of the Lakes of the Clouds Huts along the Crawford Path to the Headwall of Oakes Gulf, the Boott member of the Littleton formation is exposed and fragments of it are conspicuous in the soil.

Modern frost action can be studied in the vicinity of the Lakes of the Clouds. Just south of the Huts, miniature nets of stone chips with soft soil centers, formed by ground frost, are present. The flat upland east of the Lakes of the Clouds Huts, called Bigelow Lawn, is an excellent place to see networks of large blocks (Fig. 25) which have been pushed into rims around grassy soil centers by ground frost when the region was colder than at present. Alternate stripes of blocks of rock and grassy soil are found on the gentle slopes of Bigelow Lawn (Fig. 26). Although the block stripes are not moving today, they are indications of the active movement of blocks when frost action was more intense than at present.

The Gulfside Trail, the Westside Trail, and Davis Path follow the gently rolling upland surface at about 5000 feet, making it possible to walk the length of the Presidential Range above tree-line, with very little change in altitude. Frost action can be studied almost anywhere along the trail; block lobes, block stripes, block nets, and other features are common. There are many excellent exposures of the Littleton formation along the trail.

Mt. Washington Auto Road between the 5 and 6-mile posts passes excellent exposures of the folded beds of the sillimanite-mica schist and quartzites of the Littleton formation (Fig. 13). It is interesting to notice that the sillimanite crystals have been folded along with the bedding, indicating that they formed before the folding had been completed. The *Nelson Crag Trail* due south of the Auto Road in this same vicinity follows the swells and depressions made by the folded quartzites and schists. Glaciation has scoured the rocks in this area, leaving stream-lined ledges of rock called *"roches moutonnées,"* so that the individual beds can be easily studied.

Below the 2-mile post, along the Auto Road and south of it, the angular fragments in one of the volcanic vents may be seen (see colored geological map for location).

Huntington Ravine, with its sheer, cirque walls is one of the best places to study one of the bowl-shaped glacial depressions formed by a small mountain glacier (Fig. 23). The trail ascends a steep talus cone to a gully, or large joint crack. Blocks of the schists of the Littleton formation have split off from the jointed rocks by frost action and have avalanched down to form the talus cone. Generally the biggest blocks make up the lowest part of the cone, forming interesting caves and passages. The trail crosses one of the most spectacular black dikes of the region (Figs. 19 and 20). As the climber looks up at the south-facing cliff, the black line of the five-foot wide dike can be followed to the top of the headwall. Since the jointing in the dike is more closely spaced than the joints in the schists, the dike is quarried away more rapidly than the surrounding rocks, leaving a gully or "chimney" along the dike. Another black dike is crossed by the trail at the upper part of the headwall.

Tuckerman Ravine is a large bowl-shaped depression formed by scouring and plucking action of a small valley glacier (Fig. 22). West of the Ski Shelter, as the trail ascends the Little Headwall, at about 3700 feet elevation, the Boott

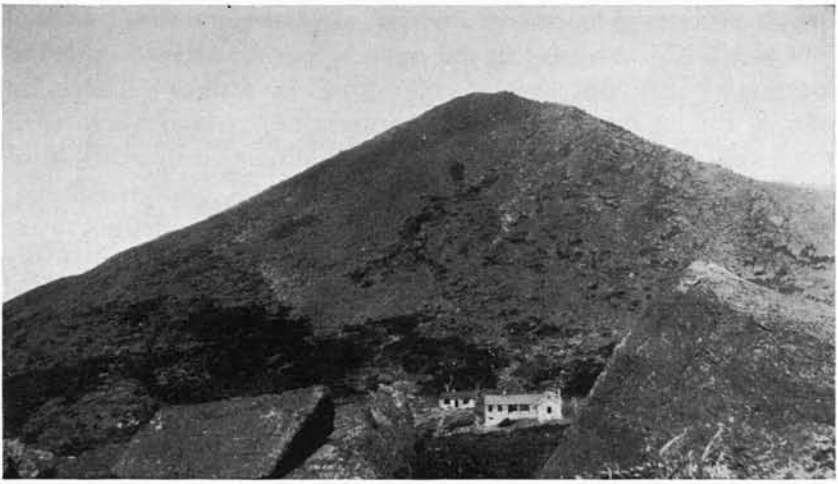


Figure 28 — Blocky cone of Mt. Madison. Madison Spring Huts in foreground. (Photo by G. Shorey.)

folds. Howker Ridge to the northeast is likewise held up by the tough, folded quartzite and schists of the Littleton formation, and is a good place to study bedding, jointing, foliation, and folds. Near the *"Parapet,"* in the col between the cones of Adams and Madison, there are well-rounded exposures of the Littleton formation (Fig. 24). Fine glacial striae are preserved on the white quartz veins. Strings of quartz boulders fan out from these quartz veins, having been plucked by glacial action. They can easily be traced back to the ledges from which they were plucked because of their distinctive color.

A little below the *summit of Mt. Quincy Adams,* on the southeast face, a large fold about 30 feet high is exposed in the Littleton formation. It appears to be flat-lying, because of the perspective of its cross-section (Fig. 17).

The *summits of Mt. Clay and Mt. Monroe* are good places to see the gneisses of the lower part of the Littleton formation. The black and white banded gneiss is well exposed on both summits.

Dome Rock, on the north end of *Gordon Ridge,* 1½ miles due south of Randolph, has excellent exposures of the thinly bedded upper part of the Littleton formation. The beds here

Figure 28 — Blocky cone of Mt. Madison. Madison Spring Huts in foreground. (Photo by G. Shorey.)

folds. Howker Ridge to the northeast is likewise held up by the tough, folded quartzite and schists of the Littleton formation, and is a good place to study bedding, jointing, foliation, and folds. Near the *"Parapet,"* in the col between the cones of Adams and Madison, there are well-rounded exposures of the Littleton formation (Fig. 24). Fine glacial striae are preserved on the white quartz veins. Strings of quartz boulders fan out from these quartz veins, having been plucked by glacial action. They can easily be traced back to the ledges from which they were plucked because of their distinctive color.

A little below the *summit of Mt. Quincy Adams,* on the southeast face, a large fold about 30 feet high is exposed in the Littleton formation. It appears to be flat-lying, because of the perspective of its cross-section (Fig. 17).

The *summits of Mt. Clay and Mt. Monroe* are good places to see the gneisses of the lower part of the Littleton formation. The black and white banded gneiss is well exposed on both summits.

Dome Rock, on the north end of *Gordon Ridge,* 1½ miles due south of Randolph, has excellent exposures of the thinly bedded upper part of the Littleton formation. The beds here member of the Littleton formation is exposed a few hundred feet south of the trail. In the main upper ravine the trail first ascends a talus cone, finally coming out on ledges. The main part of the headwall has well exposed quartzites and schists of the Littleton formation. A few hundred feet south of the trail at about 4700 feet, not far up the headwall, rounded ledges showing glacial striae can be observed. These ledges were scoured by the continental ice sheet, and are proof that the valley glacier which excavated the ravine existed before the coming of the ice sheet.

Near the upper part of the headwall, the trail follows a narrow shelf for about 400 feet. This shelf is made by one of the narrow black dikes, forming a natural footing for the trail.

Edmonds Col, the pass north of Mt. Jefferson, is an excellent place to see *"roches moutonnées"* or ledges rounded by the scouring of the continental ice sheet as it swept across the divide between Mt. Jefferson and Adams. The northwest side of each ledge, composed of well-bedded schists and quartzites of the Littleton formation, are stream-lined, whereas the southeast side is rough and steep due to glacial plucking as the ice passed over the rocks. The Gulfside Trail follows the upland surface of the Presidential Range, and Edmonds Col is one of the narrower passes between two cirques. South of the cone of Mt. Jefferson along the *Gulfside Trail,* north of Mt. Clay, there are other good examples of *roches moutonnées* in the schists and quartzites of the Littleton formation. Striking frost-built forms are present along the whole length of the Gulfside Trail, especially south of the cone of Mt. Jefferson on the south edge of "Monticello Lawn." Teardrop-shaped lobes of frost-moved blocks appear above the trail northeast of Mt. Jefferson and west of Mt. Adams.

Mt. Madison has a steep cone made up largely of huge talus blocks (Fig. 28). Near the upper part of the cone, folds in the bedded schists and quartzites of the upper part of the Littleton formation are well exposed. *Osgood Ridge,* extending to the southeast of the summit, is held up by a series of folds in the schists, the individual knobs representing small

Tama Fall, in Snyder Brook at about 1700 feet altitude, is in beautifully jointed Bickford granite. Above and below the falls there are cascades over excellent exposures of the granite (Fig. 30). Pegmatite dikes are present in several places. Downstream at *Gordon Fall* at 1400 feet, good exposures of black, banded Ammonoosuc volcanics are found.

Figure 29 — The Castellated Ridge of Mt. Jefferson, with the cirque of the Ravine of the Castles in background. The Continental Ice Sheet scoured and smoothed the rock as it moved across the ridge from left to right, plucking on the lee side. (Photo by G. Shorey.)

Figure 30 — Tama Falls, in Snyder Brook, Randolph, cascades over beautifully jointed Bickford granite. (Photo by G. Shorey.)

Cold Brook Fall is a good place to see the granitic rocks of the Oliverian magma series containing inclusions of the black Ammonoosuc volcanics. This locality is 2½ miles west-southwest of Randolph on Cold Brook, only ⅞ miles from the Ravine House. The granitic rocks are exposed between 1400 and 1480 feet, and at 1490 feet excellent exposures of the main body of the bedded volcanics begins, and can be followed upstream for some distance.

Mossy Glen, a series of cascades and rapids in the lower part of Carlton Brook in the town of Randolph, has excellent exposures of the jointed granitic rocks of the Oliverian magma series. There are many interesting waterworn potholes in the granite along the stream course.

Coösauk Fall, in Bumpus Brook at 1600 feet altitude, one mile south of Randolph Station, is over good exposures of the well-jointed, fine-grained gray Bickford granite. The gorge below the falls likewise cuts into the granite which is broken up by the jointing into great slabs or "sheets."

Hitchcock Fall, in Bumpus Brook, at 1900 feet altitude, 1½ miles south of Randolph Station is over excellent exposures of the black and white banded gneiss of the lower part of the Littleton formation.

The *Lower Falls of the Ammonoosuc River* 2¼ miles west of Bretton Woods is over beautifully jointed exposures of the Conway granite.

The *Upper Falls of the Ammonoosuc River* (1760 feet) is a splendid place to see potholes and joints in the fine-grained Bickford granite. The exposures are excellent both above and below the falls.

In the *Ammonoosuc River* along the rapids between 2080 and 2260 feet altitude, the Bickford granite is beautifully exposed.

Cherry Mountain has occasional exposures of syenite of the White Mountain magma series along the road (not shown on the map) to the Fire Tower. The sharp, conical peak of Owl's Head, the northernmost summit, has better exposures than the higher peaks. The trail on the northern slope of the mountain follows the path of an interesting landslide.

Mt. Oscar in the southwest corner of the Mt. Washington quadrangle makes an interesting bush-whack. There are beautifully glaciated ledges of the Conway granite on the summit.

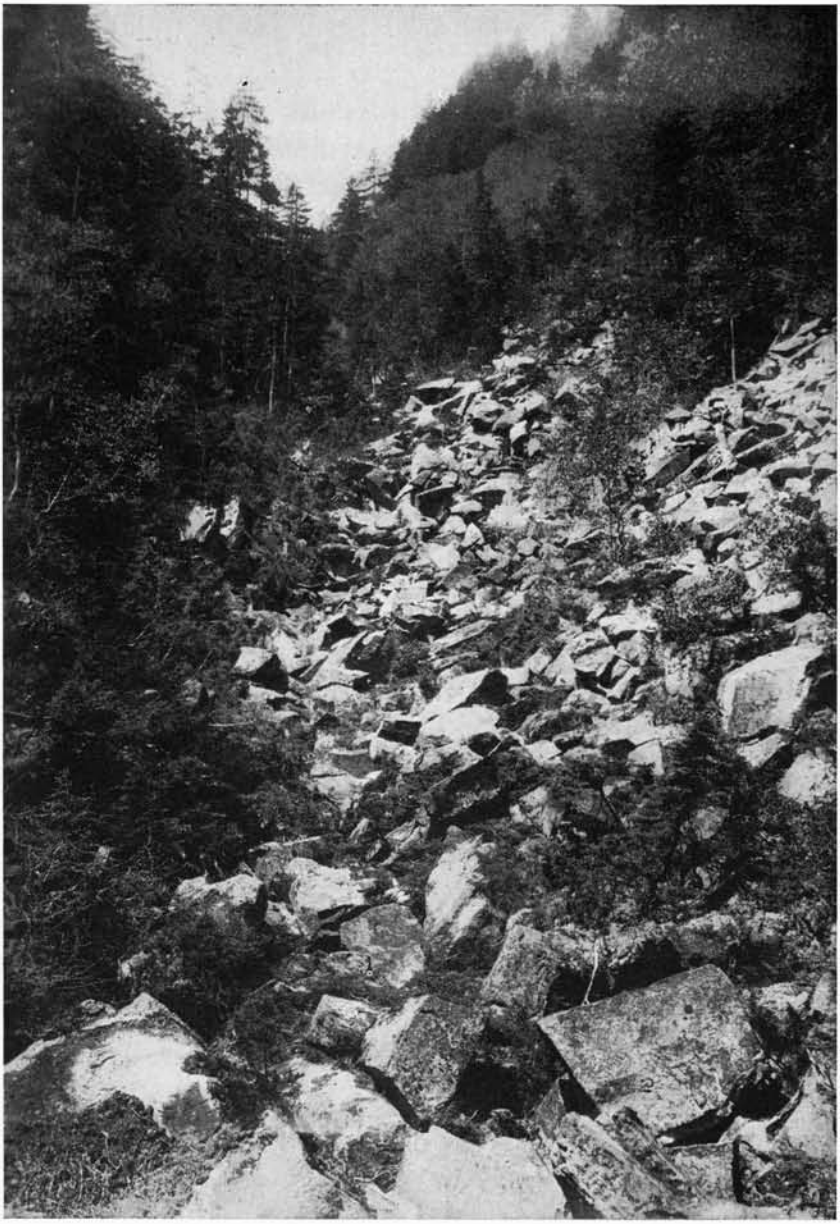


Figure 31 — The Ice Gulch at the head of Moose Brook, in the Crescent Range, is full of enormous blocks of the granite of the ring-dike. The blocks are landslide material from the valley sides. (Photo by G. Shorey.)

The views of the Presidential and Franconia Ranges are well worth the climb.

The Crescent Range ring-dike is the best exposed of the ring-dikes of the White Mountain magma series. Outcrops are particularly abundant in the vicinity of Mt. Crescent, especially on the east side of the range. There are also outcrops along the easterly flowing streams north and south of Black Crescent Mountain. A sharp contact between the ring-dike and the pink granite of the Oliverian magma series is exposed half a mile northeast of Mt. Crescent in the southeasterly flowing stream at an elevation of about 2540 feet. *Ice Gulch,* at the head of Moose Brook, runs across the eastern half of the ring-dike, and is full of enormous blocks of granite derived from the ring-dike. These blocks, which are talus or landslide material from the valley sides, have partially filled up a large gorge developed by the meltwaters of the ice sheet (Fig. 31). Ice remains unmelted all the year round amongst the blocks in the bottom of the Ice Gulch, for the sun never reaches the depths beneath the talus blocks.

Round Mountain and the two peaks to the south have good exposures of one of the ring-dikes of the Pliny Range. The technical name for the granite-like rock in this particular ring-dike is "quartz monzonite."

Mt. Starr King lies on another ring-dike south of the Round Mountain ring-dike. There are good exposures of hornblende-quartz syenite along the summit.

Mt. Cabot and Terrace Mountain are localities in the northern part of the Mt. Washington quadrangle where large bodies of granite are exposed. This granite belongs to the White Mountain magma series and contains quartzite inclusions of the Albee formation, the oldest rock in the region.

HOW TO READ THE MAP

A colored geologic map is found in the envelope in the back of the pamphlet. This map contains a wealth of information about the country itself, as well as showing the kind of rock found in each locality. The legend at the sides of the map, as well as the structure sections at the base of the map, help the reader understand and interpret the geology.

The geology has been added in color to the regular topographic map of the Mt. Washington quadrangle. One inch on the map represents approximately one mile on the ground. Automobile roads are indicated with double black lines; poor roads or logging roads as double dashed lines; trails as single dashed lines; railroads as solid black lines with cross-bars; township boundaries with long dashed lines. Houses are represented as little black squares, to which a flag is added to indicate a school house, and a cross a church. Lakes and streams are blue; swamps are blue tufts.

The shape of the hills and valleys are shown by brown lines called contour lines. Accurate altitudes are shown by black letters, which refer either to the top of a mountain, a cross road, or some other place which has been carefully determined. For instance, the top of Mt. Madison is marked 5363. This means that Mt. Madison is 5363 feet above sea level. The Pond of Safety is 2190 feet above sea level. Wherever "B. M." is written with a small cross and a number, it means that in making the survey, the topographers had an accurately calculated station at this point, or "bench mark." By studying the brown lines, or contours, you can tell the height above sea level of any point shown on the map. If you follow any single contour line, you will always keep at the same altitude, for a contour line is drawn through points of equal altitude. Since the contour interval of this map is 20 feet, it means that wherever there is a rise of 20 feet in altitude, a new contour line must be shown 20 feet above the last. To facilitate the reading of the maps, every 100-foot contour line is shown in heavy brown, and somewhere along each of these lines you will generally find a small brown number telling the exact altitude of that particular contour.

These maps will be found especially helpful in planning a hiking or fishing trip. For example, if you wished to climb Mt. Washington from Pinkham Notch by the Tuckerman Ravine Trail, you would be able to know in advance that you would have to climb from an altitude of 2032 feet at Pinkham Notch, to 6288 feet, the summit of Mt. Washington. The trip would be about four miles long, and the spacing of the contours indicates that the trail climbs steadily the whole way, with the steepest ascent on the headwall of Tuckerman Ravine, where the contours are more closely spaced. You can locate yourself by noting the places the trail crosses streams, as well as by the steepness of ascent. It would be most useful to have with you the Appalachian Mountain Club *White Mountain Guide,* with its map of the Mt. Washington Range. Details of distances, descriptions of the trails and points of general interest are included in its carefully compiled text. This map will also show the trails outside of the Mt. Washington Quadrangle, in case you wish to return to a point such as the Glen House, which is in the Gorham Quadrangle east of the Mt. Washington Quadrangle.

At the bottom of the map is a symbol labeled "approximate mean declination 1935." A line shows the direction of true north, and an arrow points to magnetic north. The angle between, indicated by 17°, means that a compass needle will point 17 degrees west of true north. This means that all magnetic compass bearings have an error of 17° in this region. This is most important if you go away from a trail and try to locate yourself by a compass. You will notice that the long edges of the map are true north-south, and the top and bottom edges of the map are true east-west lines. This fact is useful in helping you to orient yourself as to position, or to check yourself and your compass reading if you are in doubt as to the direction to take. For you can use the map as a compass, and by lining up or "sighting" certain known points on the map, you can find out the names of unknown hills by sighting to them — remembering to keep your map stationary after putting it in the correct position. The Fire Wardens use their maps in this way to locate forest fires.

The various color patterns on the map show the kinds of rock in the different localities. The legend at the side of the map is the key for finding out what each color means. In addition to the colors, each rock type is also indicated by black letters which appear scattered over the map as well as in the proper color pattern in the legend. For example, the top of Mt. Washington is shown in pale gray as well as by the letters *Dls*. In the legend, this color-pattern and the letters *Dls* are found to represent the Littleton formation of Devonian age. It is the upper part of the formation, consisting of interbedded quartzites and mica schist.

The legend is arranged with youngest rocks at the top of the left-hand column. Although the colors on the map might make you believe that rocks are exposed everywhere, this is not the case. In many places sand, glacial till and soil conceal the underlying rocks. It has been impossible to show these surface deposits on a map of this scale, except in the northwestern part of the map and in the large area around Jefferson where there is no bedrock exposed at all, and a special color-pattern and symbol "d" has been used. Elsewhere, the geologist's interpretation of the underlying bedrock, based on information gathered from actual exposures, is shown. The geological boundaries are solid black lines where it has been possible to trace them fairly accurately. Where boundaries are poorly exposed they are shown as dashed or dotted lines. The colors show only the predominant type of rock in a region, as it is impossible to show all the small pegmatites, dikes, or fragments of schist in the granitic rocks.

The three structure sections at the bottom of the map show what the rocks probably would look like if you dug a trench a mile or so deep across the area. Their positions are indicated on the map by lines labelled A-A′, B-B′, and C-C′. For example, line C-C′ goes through the top of Mt. Washington from a point north of Fabyan to about 1 mile north of Pinkham Notch. Mt. Washington is part of a truncated fold, the upper part of the Littleton formation (quartzites and schists) being exposed continuously across the mountain mass. Section B-B′ shows how the Crescent Range is held up by a wide, dike-like, vertically rising granite body, contrasting sharply with the folded beds of Mt. Washington.

There are a few "special symbols" shown on the map and in the legend. These symbols are to help interpret the structure of the rocks themselves. They represent measurments of the attitude of the rocks made by the geologist in the field. The symbols representing the "strike and dip of bedding" and "strike and dip of foliation" refer to a layering in the rocks or a layering of the minerals in the rocks (Fig. 18). The straight line of the symbol shows you the direction of "strike" or general trend of this banding or layering, and the number and pointer tells in what direction, and also how steeply this banding dips or is inclined. For example, if you take a book and place it on the table in front of you so that it looks like the roof of a house, you may easily visualize what strike and dip means (see Fig. 32). The binding is a line corresponding to the strike, or trend of a band in the rocks, while the angle of inclination of the cover would correspond to the dip of the band. You will notice that the pages of the book hang down, or "dip" at differenc angles from the horizontal. Thus, the leaves in the center are almost perpendicular to a horizontal line (vertical beds), while those to the left or right of the center vary considerably in their angles of "dip." This simile of the book and rocks should help you visualize a succession of folded rocks with lots of sheets and bands corresponding to the leaves of the book. Sometimes the leaves have been completely turned over from their original position, so that a special symbol is used in this case. Or if they lie flat, or horizontal, another symbol is used. The foliation symbols are used in the same way as those of the bedding, a special symbol being used when the foliation parallels the "axial planes" of the folds (Fig. 18).

It is by measuring the changes in direction of the bedding and foliation at every available outcrop that the geologist estimates the position of the folds in any area, thus "unravelling" the story of the rocks from a study of the measurements taken.

A special symbol is used to show breaks or "faults" in the earth's crust; a solid line, with a "U" shows which side came up in relation to the "D" or dropped-down side. If a section of the earth has been shoved or thrust over another part, a solid line with an inverted "T" is the symbol used to show this feature. If silica has welled up along the break or fault, a special symbol with an *s* shows this silicified zone.

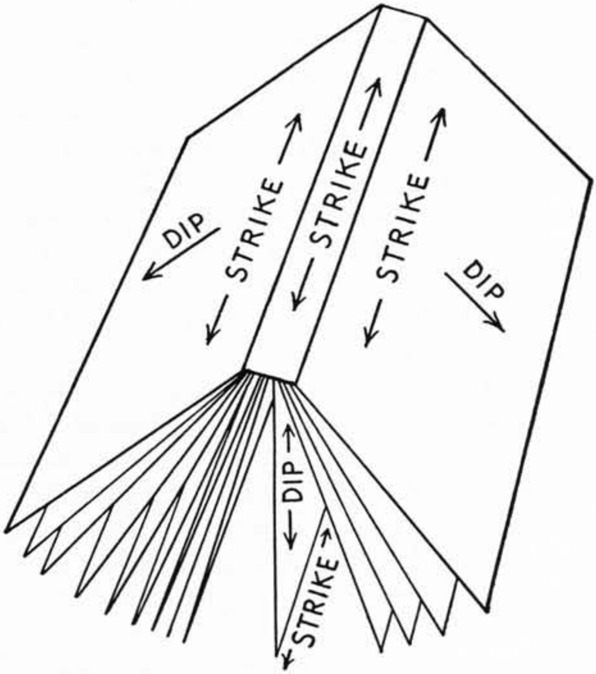


Figure 32 — Diagram to illustrate strike and dip.

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26. Goldthwait, R. P., *Mt. Washington in The Great Ice Age,* New England Naturalist, No. 5, pp. 12-19, 1939.

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34. Lougee, R. J., *Geology of the Connecticut watershed,* Biological Survey of Connecticut Watershed, New Hampshire Fish and Game Department Survey Report No. 4, Concord, N. H., 1939.

35. Lougee, R. J., *Deglaciation of New England,* Journal of Geology, vol. 3, No. 3, pp. 189-217, 1940.

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Ore Hill Zinc Mine, Warren, New Hampshire. H. M. Bannerman. 1943. 2 p. Map. Reprinted 1962.	$ .10
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Mica-bearing Pegmatites of New Hampshire. U. S. Geological Survey Bulletin. 931 p. Preliminary Report. J. C. Olson. 1941. 41 p. Maps.	Free

The following reports should be purchased directly from the Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. 20402:

Pegmatite Investigations, 1942-45, New England. U. S. Geological Survey Professional Paper 255. Eugene N. Cameron and others. 1954.	
Beryl Resources of New Hampshire. U. S. Geological Survey Professional Paper 353. James J. Page and David M. Larrabee. 1962.	$4.00
New Hampshire Basic-Data Report No. 1, Ground-Water Series, Southeastern Area. Edward Bradley and Richard G. Petersen. Prepared by the U. S. Geological Survey in cooperation with the New Hampshire Water Resources Board. 1962. 53 p. Maps. (Available from N. H. Water Resources Board, Concord, N. H.)	

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Bedrock Geology of New Hampshire. Map. 1955. Scale 1 inch equals 4 miles. 2.00

Topographic Map of New Hampshire. In three colors at scale of 1 inch equals 4 miles. 100 foot contour lines. Water areas, streams and town lines indicated. Outside dimensions 51" x 39". **Out of print.** 1.00

U. S. G. S. Quadrangle Maps. May be purchased at Division Office at 35¢ each. Large quantities of one map should be purchased directly from Director, U. S. Geological Survey, Washington 25, D. C.

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The following aeromagnetic maps are on open file at Division Office, Concord, and Geology Department, University of New Hampshire, Durham. They may be purchased for 50¢ each from Distribution Section, U. S. Geological Survey, Washington 25, D. C.

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